The effect of the knee adduction moment on tibial cartilage volume and bone size in healthy women


Objectives. There is considerable evidence that an abnormally high knee adductor moment is a characteristic of the gait patterns in people with knee osteoarthritis (OA). The aim of this study was to examine the relationship between the peak knee adduction moment during the early and late stance phases of gait, and medial and lateral tibial bone size and cartilage volume in healthy women.

Methods. Three-dimensional Vicon gait analyses and magnetic resonance imaging (MRI) were performed on 20 healthy women without knee OA. The external knee adduction moment was correlated with medial and lateral tibial bone size and cartilage volume for the dominant leg.

Results. The knee adduction moment significantly correlated with the bone size of the medial tibial plateau ($r = 0.63$, $P < 0.005$), but was not related to the bone size of the lateral plateau. No relationship was observed between the knee adduction moment and medial or lateral tibial cartilage volume.

Conclusions. Although the knee adduction moment was positively associated with the bone size of the medial tibial plateau, it appeared to have little effect on cartilage volume in that compartment in healthy women. It may be that the effect of the knee adduction moment differs in healthy subjects compared with those with established knee OA.

KEY WORDS: Knee, Adduction moment, Cartilage, Bone, Osteoarthritis.

Although increased regional load across articular cartilage is thought to be an important factor in the pathogenesis of knee osteoarthritis (OA) [1], the relationship between biomechanical factors, cartilage volume and bone size in healthy and arthritic knee joints is unclear. Whereas increased mechanical load causes adaptations in cortical and cancellous bone [2], the association between load and cartilage volume remains speculative.

The role of the knee adduction moment in OA is becoming better understood. The knee adduction moment is generated by the combination of the ground reaction force, which passes medial to the centre of the knee joint during gait, and the perpendicular distance of this force from the centre of the joint [3]. This moment tends to adduct the tibiofemoral joint, causing an increase in medial compartment pressure, and people with knee OA have demonstrated larger than normal peak knee adduction moments [4, 5] in their gait patterns. Furthermore, people with established tibiofemoral OA have reduced tibiofemoral cartilage volume compared with normal subjects [6] and have been shown to lose significant articular knee cartilage annually [7]. However, the determinants of cartilage loss remain unclear, although the knee adduction moments during gait may help to explain some of the variance in healthy and arthritic knee joint cartilage volume. Furthermore, it is possible that excessive knee adduction moments during gait may in part explain why the medial tibial plateau has a large bone size than the lateral plateau.

Although increased knee adduction moments and decreased cartilage volumes are associated with the severity of knee OA [5, 7, 8], no previous study has described the relationships between the knee adduction moment and tibial cartilage volume in healthy or arthritic knee joints. To explore the relationships between the knee adduction moment, tibial cartilage volume and bone size in normal subjects, we examined the locomotor patterns of 20 healthy women.

Methods

Subjects

Twenty women involved in an existing study of healthy ageing were recruited through the Jean Hailes Centre (a women’s health clinic) and advertising in the local media. The study was approved by the Alfred Hospital, Caulfield Hospital and La Trobe University ethics committees.

The exclusion criteria were a history of knee OA or symptoms requiring medical treatment, any knee pain for more than 1 day in the month prior to testing, radiographic evidence of OA, inflammatory arthritis, planned or previous knee joint replacement, malignancy, fracture in the last 10 yr, contraindication to MRI (e.g. pacemaker, cerebral aneurysm clip, cochlear implant, presence of shrapnel in strategic locations, metal in the eye and claustrophobia), inability to walk 15 m without the use of assistive devices, and hemiparesis.

Apparatus and procedure

Gait analyses were conducted in the gait laboratory in the Musculoskeletal Research Centre, La Trobe University, Australia. A six-camera Vicon motion analysis system (Oxford Metrics Ltd, Oxford, UK) was used to capture three-dimensional kinematic data.
data during four walking trials on the dominant leg. Each subject’s preferred kicking leg was nominated as their dominant leg. Ground reaction forces were measured by a Kistler 9281 force-platform (Kistler Instruments, Winterthur, Switzerland). Inverse dynamic analyses were performed using ‘PlugInGait’ (Oxford Metrics, Oxford, UK), which is based on a previously proposed model [9], to obtain joint moments calculated about an orthogonal axis system located in the distal segment of a joint. Inter-ASIS (anterior superior iliac spine) distance was measured using a caliper, causing the medial–lateral and proximal–distal coordinates of the hip joint centre to be determined by the method previously described [9]. The ASIS to greater-trochanter measurement provided the anterior–posterior co-ordinate of the hip joint. A knee alignment device (KAD) was used to calculate knee joint axes and tibial torsion was measured from clinical examination. The coronal plane of the thigh was defined as the plane containing the hip joint centre, knee marker and LAD 1000/600 marker. The coronal plane of the shank contained the knee joint centre and lateral malleolus marker. The angle formed by the knee and ankle joint axes measured tibial torsion.

Subjects completed a questionnaire that included demographic data and physical activity as previously described [10]. Body mass index (BMI) (weight/height\(^2\) in kg/m\(^2\)) was calculated by measuring weight to the nearest 0.1 kg (shoes and bulky clothing removed) using a single pair of electronic scales and measuring height to the nearest 0.1 cm (shoes removed) using a stadiometer.

MRI was performed on each subject’s dominant knee. Knee cartilage volume was determined by image processing on an independent workstation using the Osiris software (University of Geneva) as previously described [11]. Knees were imaged in the sagittal plane on the same 1.5-T whole-body magnetic resonance unit (Signa Advantage HiSpeed GE Medical Systems Milwaukee, WI) using a commercial receive-only extremity coil. Medial and lateral tibial plateau bone sizes (surface area) were determined by creating an isotropic volume from the input images reformatted in the axial plane and plateau bone size was directly measured from these images as previously described [6]. The coefficients of variation for medial and lateral tibial plateau size were 2.3 and 2.4%, respectively, and the coefficients of variation for the measurement of medial and lateral cartilage volume measures were 3.2 and 2.7%, respectively.

### Statistical analysis

Pearson’s correlations were used to examine the relationship between the peak knee adduction moment during early and late stance, the medial and lateral tibial bone size, and cartilage volume. Prior to calculating a coefficient, the scatterplots of the associations were inspected for features that would impede interpretation, such as non-normality of the two variables, non-linearity of the association and outlying observations. All analyses were performed for the dominant leg since combining the right and left leg fails to acknowledge independence between knees and the potential for asymmetrical alignment of the lower limbs. By selecting the dominant leg, we attempted to control for variables that may be joint specific rather than subject specific. Results where there were \( P \) values of less than 0.05 (two-tailed) were considered to be statistically significant. All analyses were performed using SPSS (version 11.0.1, SPSS, Cary, NC).

### Results

The mean age of the 20 participating women was 61.0 ± 5.3 yr. The mean BMI was 25.3 ± 4.2 kg/m\(^2\). The mean level of current physical activity was 7.7 ± 2.4 (on a scale of 0–12, where 0 represented no physical activity). The mean magnitudes and standard deviations for the knee adduction moments, bone sizes and cartilage volumes are presented in Table 1.

### Knee adduction moment and tibial bone size

The peak knee adduction moment during late stance was significantly associated with the medial tibial bone size (\( r = 0.63, P = 0.004 \)). This relationship remained significant after post-hoc Bonferroni adjustments (\( \alpha = 0.006 \)). No significant correlation was observed between the knee adduction moment during late stance and the lateral tibial bone size. The peak adduction moment during early stance was not significantly associated with the medial or lateral tibial bone size. Adjustment for age, BMI and physical activity did not change the results presented in Table 2.

### Knee adduction moment and tibial cartilage volume

No significant correlations were observed between the peak adduction moment occurring during early or late stance and the medial or lateral tibial cartilage volume prior to and after adjustment for age, BMI and physical activity. These results are presented in Table 2.

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**Table 1.** Mean magnitudes of biomechanical and MRI data

<table>
<thead>
<tr>
<th></th>
<th>Mean</th>
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</thead>
<tbody>
<tr>
<td>Knee adduction moment (early stance)(^b)</td>
<td>4.0 (0.94)</td>
</tr>
<tr>
<td>Knee adduction moment (late stance)(^b)</td>
<td>2.2 (0.67)</td>
</tr>
<tr>
<td>Medial cartilage volume (ml)</td>
<td>1651 (345)</td>
</tr>
<tr>
<td>Lateral cartilage volume (ml)</td>
<td>2071 (362)</td>
</tr>
<tr>
<td>Medial bone size (mm(^3))</td>
<td>1654 (171)</td>
</tr>
<tr>
<td>Lateral bone size (mm(^3))</td>
<td>1051 (115)</td>
</tr>
</tbody>
</table>

\(^a\)Results reported as mean ± standard deviation.  
\(^b\)Adduction moments are normalized to percentage body weight multiplied by height.

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**Table 2.** Correlations between the knee adduction moment, tibial cartilage volume and bone size after adjustment for age, weight, height and physical activity

<table>
<thead>
<tr>
<th></th>
<th>Adduction moment (early stance)</th>
<th>Adduction moment (late stance)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>( r ) ( P )</td>
<td>( r ) ( P )</td>
</tr>
<tr>
<td>Medial cartilage volume</td>
<td>-0.06 0.79</td>
<td>0.02 0.92</td>
</tr>
<tr>
<td>Lateral cartilage volume</td>
<td>-0.15 0.54</td>
<td>0.01 0.98</td>
</tr>
<tr>
<td>Medial bone size</td>
<td>0.32 0.17</td>
<td>0.63 0.003</td>
</tr>
<tr>
<td>Lateral bone size</td>
<td>-0.22 0.39</td>
<td>-0.21 0.39</td>
</tr>
</tbody>
</table>

\( r \), Spearman’s correlation coefficient.
Discussion

To our knowledge, this is the first study describing the relationship between the knee adduction moment, tibial bone size and cartilage volume in healthy women. Although the knee adduction moment provides a major contribution to the 70% of total knee joint load passing through the medial tibiofemoral compartment during walking [4], these results suggest that the moment influences bone size to a greater extent than cartilage volume in healthy knees.

The peak knee adduction moment during late stance was correlated with the medial tibial plateau bone size, yet not the lateral plateau. The greater the magnitude of the knee adduction moment in normal subjects, the larger the medial tibial plateau bone size. This substantiates the knee adduction moment’s influence on medial joint load and provides evidence supporting the role mechanical load plays in the regulation of new bone growth [12]. Although a relationship between the knee adduction moment and medial tibial plateau bone size was apparent during late stance, this was not observed during early stance. It may be that internal activity of soft tissues provided by structures such as ligaments and muscles helps to better restrain the compressive force imposed on the medial tibiofemoral compartment by the adduction moment during early stance, compared with late stance. Moreover, it may be that the increased load experienced by the supporting limb during late stance mediated the association between the knee adduction moment and the medial bone size. Further work is required to substantiate the complex spatial and temporal interaction involving the knee adduction moment during walking [13].

To our knowledge, only two other studies have examined the influence of the knee adduction moment on bone adaptation at the knee. These showed that the knee adduction moment was the single best predictor of the medial to lateral ratio of proximal bone mineral content in normal [14] and arthritic subjects [15]. While the knee adduction moment appears to be an important factor regulating bone size and mineral content in healthy and arthritic subjects, whether the adduction moment’s relationship with bony changes at the proximal tibia influences the risk of developing OA needs to be examined by longitudinal studies.

No relationship was observed between the knee adduction moment and medial or lateral tibial cartilage volume. No previous study has examined the relationship between the adduction moment and cartilage volume in healthy or arthritic subjects. Previous studies examining people with knee OA showed that a larger adduction moment was associated with greater medial joint space narrowing [5, 8]. However, because knee joint space consists of other structures such as menisci, joint space narrowing is not always a valid indicator of articular cartilage volume [16]. There is, however, emerging evidence that cartilage volume will be a useful measure in studies of the pathogenesis of OA [17–20]. A recent study that examined subjects with early radiographic OA demonstrated that medial joint space narrowing was associated with substantial reductions in cartilage volume at both medial and lateral tibial and patella compartments [G Jones, CH Ding, FS Scott, M Glisson, FM Ciccuitini, personal communication]. Furthermore, osteophytosis was associated with substantial increases in lateral and medial tibial joint surface area, but not with a change in cartilage volume [G Jones, CH Ding, FS Scott, M Glisson, FM Ciccuitini, personal communication]. This may infer that the changes in cartilage and bone morphology in early OA are independent of each other. Given that this study demonstrated that the knee adduction moment was associated with a change in the medial tibial plateau bone size in healthy people, it may be that bone size plays a role in the initiation of disease, while alterations in cartilage volume may mediate disease progression. Further work is required to elucidate the response of cartilage and bone to mechanical load before and after disease onset.

The findings of this study are limited by the relatively small sample size, although we did have sufficient power to show the effect of adductor moment on bone size. However, our results do suggest that the effect on cartilage, if any, is significantly less than the effect on bone. The extent to which these findings generalize to men will require further investigation.

Although this study has demonstrated a positive association between the knee adduction moment and the size of the medial tibial plateau in healthy women, no relationship between the adduction moment and the medial cartilage volume was apparent. It may be that the knee adductor moment has a different effect on joint cartilage in healthy subjects compared with those with established knee OA. Further work is required to elucidate the typical response of cartilage to mechanical load and examine whether changes in bone size predate the onset of disease.

The authors have declared no conflicts of interest.

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References